UNCLASSIFIED

AD 296 522

Reproduced
by the

ARMED SERVICES TECHNICAL INFORMATION AGENCY
ARLINGTON HALL STATION
ARLINGTON 12, VIRGINIA

UNCLASSIFIED

NOTICE: When government or other drawings, specifications or other data are used for any purpose other than in connection with a definitely related government procurement operation, the U. S. Government thereby incurs no responsibility, nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications, or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use or sell any patented invention that may in any way be related thereto.

63-2-4

296 522

CATALOGED BY ASTIA
AS AD NO. 296 522

CORNELL AERONAUTICAL LABORATORY, INC.
OF CORNELL UNIVERSITY

BUFFALO, N. Y.

ANNUAL REPORT

Project PARA
(Perceiving and Recognition Automata)

1 January 1962 - 31 December 1962

Contract Nonr-2381(00)

Prepared by:

J. L. Muerle
Project Engineer

JLM:pjw-7

Approved by:

H. R. Leland, Head
Cognitive Systems Branch

for W. S. Holmes, Head
Computer Research Department

1.0 Project Objectives

The objective of Project PARA is to pursue applied research in the application of perceptrons to practical pattern recognition and control problems.

2.0 Project Activity and Accomplishments

The major areas of project activity and accomplishments in each of these areas during the reporting year were: character recognition, cataloging potential applications, and perceptrons as dynamic controllers.

2.1 Recognition of imperfect, mixed-font, alpha-numeric characters

The feasibility of the recognition of mixed-font, alpha-numeric characters in the presence of noise using a three-layer, simple perceptron was experimentally verified. Character recognition experiments were performed, using perceptrons simulated on CAL's IBM-704, with characters taken from real life. The perceptron simulation programs (written just prior to this reporting year) provide retinal matrices up to 128 elements square, up to 50,000 A-units, and as many R-units as are desired. The characters used as stimuli for the experiments are taken from the two local newspapers and a CAL addressograph. Both retouched clean versions and the real-life noisy versions were used.

Experimental results indicated that a perceptron having only 100 to 200 A-units could be trained to perfect recognition of a training stimulus set which contains three different fonts of clean characters. Included in this set are upper and lower case letters and the numerals. Perceptrons trained on these clean characters to recognize one of the characters (single R-unit perceptrons) were able to distinguish about

two thirds of the noisy characters from the character on which they were trained.

Two sources of difficulty in attaining high character recognition capability were discovered during these experiments. The first problem is the obvious one of how to handle the recognition of noisy characters with a perceptron. Training with clean characters is not adequate. Training with noisy characters is a possibility, but is expensive in both stimulus preparation time and training time. The second problem is the recognition of characters translated on the retina to a position different from that on which training was carried out. It was determined that a very small amount of translation can cause poor recognition.

The problem of the recognition of noisy characters prompted a review of some work started late in 1961 on building a mathematical model of the noise present around the characters and then generating A-unit to R-unit weights based on the statistics of the noise model and the frequency of A-unit activity associated with each stimulus class. A more complete description of this noise theory is given in Appendix B.

2.2 Perceptron applications catalog

A lengthy list of potential perceptron applications was prepared in mid-1962 for the dual purposes of uncovering feasible new applications which might be of broad interest to the Navy and of selecting areas for future research on this project. The initial list was purposely prepared without any actual consideration of feasibility and was then refined by discussion at CAL, and, later, discussions with ONR personnel. One of the most interesting applications was that of using a perceptron to control a physical system having a number of parameters interrelated dynamically in such a way as to tend to make the system unstable. A problem of this type is now being investigated on the project.

2.3 Multi-dimensional, adaptive control system

The technique for using a perceptron to provide control of a dynamic system is to train it during human control of the system and then, after training, allow the trained perceptron to make corrective control movements and adjustments without human intervention. Of particular interest is the control of a system which has a number of performance requirements interrelated in such a way as to tend to make it unstable. Control of a helicopter is such a problem, but it is much too complicated to be tractable for a modest, exploratory experiment. The helicopter control problem can be simplified, however, to the point where it still remains a challenging control problem for a human controller and at the same time simple enough for a small perceptron. Such a simplified but still challenging problem has been isolated and initial work on an experiment was started during the reporting year. Planning for this research constituted a major effort during the reporting year and, therefore, the experimental plans and equipment are discussed in some detail in the following paragraphs.

The experimental plan is to simulate the dynamics of a system having control problems similar to those of a hovering helicopter on a computer, in real time, with external controls for a human operator. Provision for real time calculations is made by adding a clock input to the computer. A joy stick will be used for input and a visual display for output, with the joy stick controlling the rotor tip plane angle of the simulated simplified helicopter and the visual display indicating pitch and roll of the tip plane and the position of the helicopter.

The perceptron simulation which will be used in the control experiments will be essentially the same as that used for the character recognition experiments discussed above, but the input patterns will be coded

information concerning course to be traveled or position to be reached, pitch and roll of the simplified helicopter, and some time history of position, pitch, and roll. The R-unit output corresponds to commands such as those provided by the joy stick with a human pilot (rotor tip plane angle). We will attempt to find the parameters of the perceptron providing good control.

The experiments to be performed will consist of a training sequence followed by a testing sequence. Initially a goal will be established. The goal will consist of "flying" to a given destination starting from a reference starting position or of "flying" along a fixed course starting from a reference starting position. During training the human operator will "fly" to the given destination or on the given course using the joy stick and the vehicle dynamics simulated in the computer. The perceptron will observe the patterns of inputs and its R-unit commands will be compared with the command actions of the human pilot. After training, testing will consist of perceptron control of the "flight" using the same simulated vehicle dynamics. Successful training of the perceptron can be measured by the accuracy and speed with which the goal is attained. Figures 1 and 2 in Appendix A are block diagrams of the experimental system under training and testing, respectively.

The experimental runs will range over about 10 seconds, and the range of position, displayed on 5" cathode ray oscilloscope, will be defined by a 64 x 64 point grid. A bright spot on the screen will indicate position, a line segment connected to the bright spot will indicate pitch, and tick marks on the edge of the screen will indicate roll.

The electrical design of the equipment necessary to read pitch and roll from a joy stick and time from a clock into the CAL IBM-704 computer has been completed. The electrical design of the equipment necessary to

display pitch and roll and position on an oscilloscope has been completed and construction of the first chassis is started. Planning the modifications of the perceptron simulation programs, the generation of the simplified helicopter simulation program, the data handling and conversion programs, and the master program to monitor the whole system is under way.

3.0 Publications

The paper "Recognition of Mixed-Font Imperfect Characters" by W. S.. Holmes, H. R. Leland, and J. L. Muerle was published in the book Optical Character Recognition edited by G. L. Fischer, Jr., D. K. Pollock, B. Raddack, and M. E. Stevens and published in 1962 by Spartan Books of Washington, D.C.

APPENDIX A
BLOCK DIAGRAMS OF PERCEPTRON CONTROLLING A DYNAMIC SYSTEM

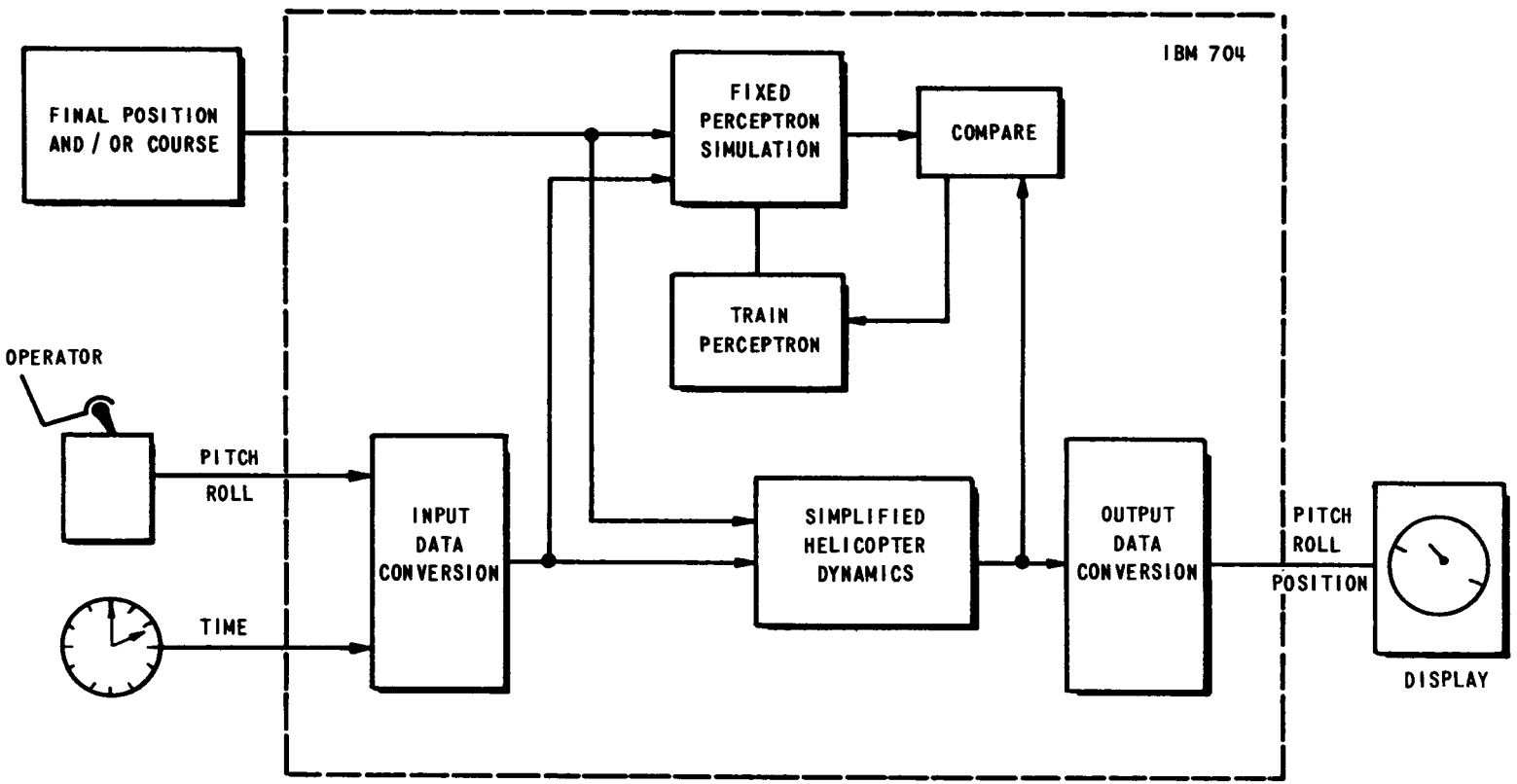

Figure 1 BLOCK DIAGRAM OF EQUIPMENT DURING TRAINING OF PERCEPTRON

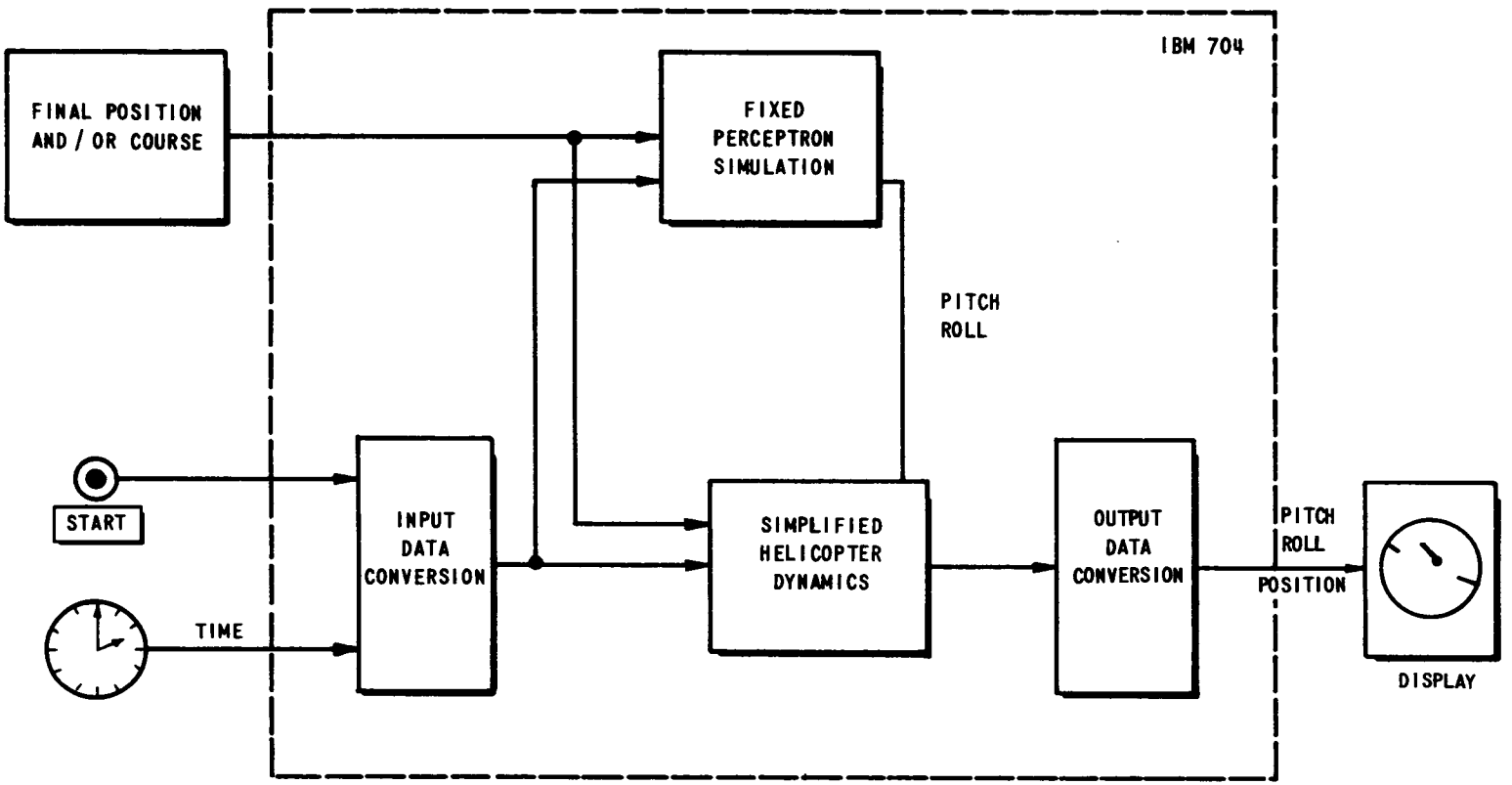

Figure 2 BLOCK DIAGRAM OF EQUIPMENT DURING TESTING OF PERCEPTRON CONTROL

APPENDIX B

WEIGHTS AND ERRORS PROBABILITY FOR DISCRIMINATION IN A NOISY ENVIRONMENT

APPENDIX B

WEIGHTS AND ERRORS PROBABILITY FOR DISCRIMINATION IN A NOISY ENVIRONMENT

B. 1 Summary

This Appendix describes a method for calculating the A-unit weights to be used in a simple perceptron operating in a noisy environment. The (binary) patterns to be discriminated consist of a set of prototypes divided into two classes and corrupted by noise. The noise is characterized by two parameters: the probability that a cell which is a one in the prototype will become a zero, and the probability that a cell which is a zero in the prototype will become a one. Using appropriate independence assumptions, the statistics of the retinal output, the input to an A-unit before thresholding, and the output of an A-unit are computed in turn. The latter provides sufficient information to compute Bayes' rule weights. These results are then used to derive the probability of misclassification.

B. 2 Introduction

Previous attempts to introduce the effects of noise in pattern recognition apparatus of the perceptron class have assumed that noisy versions of the stimuli will be used in training, thus implicitly introducing the effects of noise, or have assumed that a system trained on noise-free patterns will operate satisfactorily in the presence of noise. The first method suffers from the need for a very large sample and consequently long training periods in order to have some assurance of satisfactory performance. The second method is less satisfactory than the first.

This discussion follows the lead of current statistical communication theory and proceeds as follows:

1) Set up a mathematical model of the noise.

2) Derive the statistical properties of the proposed discrimination technique in the presence of the noise.

Training is not discussed - in fact it is ignored. Recent experimental results obtained at CAL show that, at least in the absence of noise, very satisfactory discrimination is obtained using weights derived from Bayes' rule. Here we will attempt to describe performance with Bayes' rule weights. If better performance is desired, it is probably easier and cheaper to add A-units than to use a training technique.

B.3 Noise Model

We consider that the classes to be discriminated consist of binary prototype patterns fixed with respect to the retina, with noise. Specifically excluded in this analysis are the effects of translation, rotation, and scale change, and any interactions of noise with such transformations, or with mechanisms designed to remove their effects. Transformed patterns can, of course, be included as additional prototypes.

The noise is defined by two parameters:

p_{01}, the probability that a retinal point which is a zero in the prototype will be changed to a one by noise;

p_{10}, the probability that a retinal point which is a one in the prototype will be changed to a zero by noise.

It is also assumed that the noise at each retinal point is statistically independent. We justify this assumption below.

Using this model we find expressions for some useful quantities.

Let r be the output from some specific retinal point.

For a point for which $r = 1$ in the prototype:

$$E(r) = 1 - p_{10} \tag{B-1}$$

$$E(r^2) = 1 - p_{10} \tag{B-2}$$

$$V(r) = p_{10}(1 - p_{10}) \tag{B-3}$$

For a point for which $r = 0$ in the prototype:

$$E(r) = p_{01} \tag{B-4}$$

$$E(r^2) = p_{01} \tag{B-5}$$

$$V(r) = p_{01}(1 - p_{01}) \tag{B-6}$$

Here $E(u)$ is the expected value of u and $V(u)$ the variance of u over an ensemble of stimuli derived from the same prototype.

B.4 Machine Model

The pattern recognition machine studied here is familiar as the simple perceptron. It consists of a number of A-units, whose inputs are randomly selected and have unit positive or negative weights. These inputs are summed and compared against a threshold. If the threshold is exceeded, the output of the A-unit is 1, otherwise it is zero. The A-unit outputs are collected in a weighted sum which is again thresholded to produce a classification output.

The symbols used are as follows:

- N = total number of inputs to an A-unit
- N_e = number of positively weighted inputs to an A-unit
- N_i = number of negatively weighted inputs to an A-unit
- A = total input to the A-unit for the prototype pattern
- a = total input to the A-unit for an arbitrary pattern
- $N_{e,0}$ = number of positively weighted inputs which are zero in the prototype
- $N_{e,1}$ = number of positively weighted inputs which are one in the prototype

$N_{i,0}$ and $N_{i,1}$ are defined similarly

Note that $N_{e,0} + N_{e,1} = N_e$ (B-7)

$$N_{i,0} + N_{i,1} = N_i \tag{B-8}$$

$$N_e + N_i = N \tag{B-9}$$

$$A = N_{e,1} - N_{i,1} \tag{B-10}$$

X = output from the A-unit

Some of the above symbols may acquire additional subscripts when it is necessary to distinguish various prototype patterns.

Since the inputs to the A-unit are selected at random over the retina, any strictly local dependence of the noise will have no effect on the assumed independence of the noise on the various inputs.

The A-unit input a is a random variable which can assume only integral values. Its probability density (for a particular A-unit) can be defined rigorously in terms of the parameters given above and the binomial distribution. The work is tedious and not very illuminating. Let us pass directly to a Gaussian approximation to this probability density. The work is faciliated by the following table which summarizes the A-unit input situation using data from: Equations B-1 through B-6.

Weight	Value of r in Prototype	E(r)	V(r)	Number of Occurrences
1	0	p_{01}	$p_{01}(1-p_{01})$	$N_{e,0}$
1	1	$1-p_{10}$	$p_{10}(1-p_{10})$	$N_{e,1}$
-1	0	p_{01}	$p_{01}(1-p_{01})$	$N_{i,0}$
-1	1	$1-p_{10}$	$p_{10}(1-p_{10})$	$N_{i,1}$

From the above we compute the expected value and variance of a.

$$E(a) = N_{e,0}P_{01} + N_{e,1}(1-P_{10}) - N_{i,0}P_{01} - N_{i,1}(1-P_{10}) \quad \text{(B-11)}$$

$$V(a) = N_{e,0}P_{01}(1-P_{01}) + N_{e,1}P_{10}(1-P_{10}) + N_{i,0}P_{01}(1-P_{01}) + N_{i,1}P_{10}(1-P_{10}) \quad \text{(B-12)}$$

The relations (B-7) to (B-10) can be used to reduce the above to the following forms:

$$E(a) = A(1 - p_{10} - p_{01}) + (Ne - N_i)p_{01} \tag{B-13}$$

$$V(a) = Np_{01}(1-p_{01}) + (2Ne_{,1} - A)[p_{10}(1-p_{10}) - p_{01}(1-p_{01})] \tag{B-14}$$

Other forms are of course possible. If we assume that a Gaussian distribution having the parameters given in (B-13) and (B-14) can be used to evaluate the cumulative probability for a we can pass directly to the probability of activity of the A-unit for this prototype.

$$\text{Prob}\ (\chi = 0) = G\left(\frac{\theta \cdot E(a)}{(V(a))^{1/2}}\right) \tag{B-15}$$

$$\text{Prob}\ (\chi = 1) = 1 - \text{Prob}\ (\chi = 0) \tag{B-16}$$

Where θ is the A-unit threshold and must be an integer + $\frac{1}{2}$

$G(u) = \int_{-\infty}^{u} \frac{1}{\sqrt{2\pi}} e^{-t^2/2}$ dt, a tabulated function.

B.5 Weight Analysis

Equations (B-15) and (B-16) define completely the probability density for a single A-unit output given that the input is derived from a specific prototype, in terms of the noise statistics and the A-unit connection parameters. We now assume the existence of two sets of prototypes which this machine is to attempt to classify correctly using a Bayes' rule classification function. The only other assumption necessary to derive what follows is that the A-unit outputs are statistically independent. This is much harder to accept than the previous independence assumption, but it is supported by recent experimental work at CAL.

The independence assumption leads by a well-known route to the classification function

$$f = \log \frac{\pi_1}{\pi_0} + \sum \log \frac{p_1^{(i)}(x_i)}{p_0^{(i)}(x_i)} \qquad \text{(B-17)}$$

Where π_1 is the prior probability of class 1

π_0 is the prior probability of class 0

$p_1^{(i)}(x_i)$ is the probability density for the ith A-unit output given that the input belongs to class 1

$p_0^{(i)}(x_i)$ is defined similarly.

If $f > 0$ we say the input belongs to class 1; otherwise to class 0.

Since the x_i are binary, the function

$$\log \frac{p_1^{(i)}(x_i)}{p_0^{(i)}(x_i)}$$

can be written in the form $w_i x_i + b_i$, where

$$w_i = \log \left[\frac{p_1^{(i)}(1)\ p_0^{(i)}(0)}{p_0^{(i)}(1)\ p_1^{(i)}(0)} \right] \qquad \text{(B-18)}$$

$$b_i = \log \frac{p_1^{(i)}(0)}{p_0^{(i)}(0)} \qquad \text{(B-19)}$$

Thus (B-17) reduces to

$$f = \left(\log \frac{\pi_1}{\pi_2} + \sum_i b_i + \sum_i w_i x_i \right. \qquad \text{(B-20)}$$

We wish now to use previously developed expressions to define w_i and b_i in terms of A-unit parameters and prototype data.

Let X_{ij} = probability that the i^{th} A-unit output (x_i) is 1 for the j^{th} prototype

R_j = prior probability of the j^{th} prototype

C_0 = set of indices of those prototypes belonging to class zero

C_1 is similarly defined

Now $$X_{ij} = 1 - G\left(\frac{\theta - E(a_{ij})}{[V(a_{ij})]^{1/2}}\right) \tag{B-21}$$

from (15) and (16)

$$p_0^{\,i}(1) = \frac{1}{\pi_0} \sum_{j \in C_0} R_j X_{ij} \tag{B-22}$$

$$p_0^{(i)}(0) = 1 - p_0^{(i)}(1) \tag{B-23}$$

$$p_1^{(i)}(1) = \frac{1}{\pi_1} \sum_{j \in C_1} R_j X_{ij} \tag{B-24}$$

$$p_1^{(i)}(0) = 1 - p_1^{(i)}(1) \tag{B-25}$$

$$\pi_0 = \sum_{j \in C_0} R_j \tag{B-26}$$

$$\pi_1 = \sum_{j \in C_1} R_j \tag{B-27}$$

$$\pi_0 + \pi_1 = 1 \tag{B-28}$$

Equations (B-13), (B-14), and (B-21) through (B-28) define all the quantities necessary to compute W_i and b_i from Equations (B-18) and (B-19).

B.6 Error Probability

The intent of the following is to develop an expression for the probability of misclassification using the results already obtained.

Assumptions:

1) The x_i are independent

2) The probability density of f can be approximated by a Gaussian.

Let E = probability of misclassification

f_0 = the classification variable when the input belongs to class 0

f_1 = is similarly defined.

$$E = \pi_0 \text{ (Prob. } f_0 > 0 \text{)} + \pi_1 \text{ (Prob. } f_1 < 0 \text{)} \tag{B-29}$$

The means and variance of f_0 can be found from (B-20) using the following relations:

$$\left.\begin{aligned} E(x_i) &= p_0^{(i)}(1) \\ V(x_i) &= p_0^{(i)}(0)\,p_0^{(i)}(1) \end{aligned}\right\} \quad \text{when the input belongs to class 0} \tag{B-30}$$

$$E(f_0) = \log \frac{\pi_1}{\pi_0} + \sum_i b_i + \sum_i W_i\, p_0^{(i)}(1) \tag{B-32}$$

$$V(f_0) = \sum_i W_i^2\, p_0^{(i)}(0)\, p_0^{(i)}(1) \tag{B-33}$$

Similarly,

$$E(f_1) = \log \frac{\pi_1}{\pi_0} + \sum_i b_i + \sum_i W_i\, p_1^{(i)}(1) \tag{B-34}$$

$$V(f_1) = \sum_i W_i^2\, p_1^{(i)}(0)\, p_1^{(i)}(1) \tag{B-35}$$

Using (B-32) - (B-35) in (B-29) yields

$$E = \pi_0\left[1 - G\left(\frac{-E(f_0)}{[V(f_0)]^{1/2}}\right)\right] + \pi_1\, G\left(\frac{-E(f_1)}{[V(f_1)]^{1/2}}\right) \qquad \text{(B-36)}$$

which is the desired result.

B.7 Special Case of Discrimination in a Noisy Environment

Special cases are often useful in furthering understanding. With this objective, we consider the following specialization of the general results described above.

B.7.1 Assumptions

The following additional assumptions are used:

1) The noise is symmetric $p_{01} = p_{10} = p$ (B-37)

2) The number of excititory connections is equal to the number of inhibitory connections.

$$N_e = N_i = N/2 \qquad \text{(B-38)}$$

3) There are only two input prototypes, one of each class

It is interesting to note that the reduced problem is very much like signaling over a binary symmetric channel, a much-analyzed problem of communication theory.

B.7.2 Results

Using the assumptions, key results of the reference become as follows:

(B-13) $$E(a_{ij}) = A_{ij}(1-2p) \qquad \text{(B-39)}$$

(B-14) $$V(a_{ij}) = Np(1-p) \qquad \text{(B-40)}$$

(B-21) $$X_{ij} = 1-G\left(\frac{\theta - E(a_{ij})}{[V(a_{ij})]^{1/2}}\right) \qquad \text{(B-41)}$$

(B-22) $$p_0^{(i)}(1) = X_{io} \tag{B-42}$$

(B-24) $$p_1^{(i)}(1) = X_{i1} \tag{B-43}$$

Using (B-41), (B-42), (B-43), (B-23), and (B-25):

$$p_0^{(i)}(0) = G\left(\frac{\theta - E(a_{io})}{[V(a_{io})]^{1/2}}\right) \tag{B-44}$$

$$p_1^{(i)}(0) = G\left(\frac{\theta - E(a_{i1})}{[V(a_{i1})]^{1/2}}\right) \tag{B-45}$$

Equation (B-18) may be transformed as follows:

$$W_i = \log\left[\frac{1}{p_1^{(i)}(0)} - 1\right] - \log\left[\frac{1}{p_0^{(i)}(0)} - 1\right] \tag{B-46}$$

Substitution of (B-44) and (B-45) in (B-46) leads to functions of the form $\log\left[\frac{1}{G(\mu)} - 1\right]$. Some computation supplemented by a small amount of analysis yields the following surprisingly good approximation:

$$\ln\left[\frac{1}{G(\mu)} - 1\right] \approx -2\sqrt{\frac{2}{\pi}}\,\mu \tag{B-47}$$

Using (B-47) and henceforth taking all logarithms to the base e:

$$W_i = -2\sqrt{\frac{2}{\pi}}\left(\frac{\theta - E(a_{i1})}{[V(a_{i1})]^{1/2}}\right) + 2\sqrt{\frac{2}{\pi}}\left(\frac{\theta - E(a_{io})}{[V(a_{io})]^{1/2}}\right) \tag{B-48}$$

We may now use (B-39) and (B-40) in (B-48) and note a gratifying amount of cancellation.

$$W_i = 2\sqrt{\frac{2}{\pi}}\,\frac{1-2p}{\sqrt{Np(1-p)}}\,[A_{i1} - A_{io}] \tag{B-47}$$

Note that any positive multiple of f , the classification function, is as good as the original. Let us, therefore, let

$$f^* = \frac{\sqrt{\pi N p(1-p)}}{2\sqrt{2}\,(1-2p)}\ f \qquad \text{(B-50)}$$

Note that we must make the restriction $p < \frac{1}{2}$.

Then (B-20) becomes:

$$f^* = T + \sum_i (A_{i1} - A_{i0})\, x_i \qquad \text{(B-51)}$$

$$T = \frac{\sqrt{\pi N p(1-p)}}{2\sqrt{2}\,(1-2p)} \left(\log \frac{\pi_1}{\pi_0} + \sum_i b_i \right. \qquad \text{(B-52)}$$

B.7.3 Intepretation

Note that the weights as expressed in (B-51) depend only on the pre-threshold A-unit input for the two prototypes. Thus, if the assumptions are met, we can readily fix the weights in advance without knowledge of the degree of noisiness of the environment. The decision threshold T is a complex expression whose significance is not yet known. It is possible that it depends only weakly upon p .

DISTRIBUTION LIST

Assistant Secretary of Defense for Research and Engineering (2)
Information Office Library Branch
Pentagon Building
Washington 25, DC

Armed Services Technical Information Agency (10)
Arlington Hall Station
Arlington 12, Virginia

Chief of Naval Research (2)
Department of the Navy
Washington 25, DC
ATTN Code 437, Information Systems Branch

Chief of Naval Operations (1)
OP-07T-12
Navy Department
Washington 25, DC

Director, Naval Research Laboratory (6)
Technical Information Officer, Code 2000
Washington 25, DC

Commanding Officer, Office of Naval Research (10)
Navy #100, Fleet Post Office
New York, New York

Commanding Officer, ONR Branch Office (1)
346 Broadway
New York 13, New York

Commanding Officer, ONR Branch Office (1)
495 Summer Street
Boston 10, Massachusetts

Bureau of Ships (1)
Department of the Navy
Washington 25, DC
ATTN Code 607A NTDS

Bureau of Naval Weapons (1)
Department of the Navy
Washington 25, DC
ATTN RAAV Avionics Division

Bureau of Naval Weapons (1)
Department of the Navy
Washington 25, DC
ATTN RMWC Missile Weapons Control Division

Bureau of Naval Weapons (1)
Department of the Navy
Washington 25, DC
ATTN RUDC ASW Detection and Control Division

Bureau of Ships (1)
Department of the Navy
Washington 25, DC
ATTN Communications Branch Code 686

Naval Ordnance Laboratory (1)
White Oaks
Silver Spring 19, Maryland
ATTN Technical Library

David Taylor Model Basin (1)
Washington 7, DC
ATTN Technical Library

Naval Electronics Laboratory (1)
San Diego 52, California
ATTN Technical Library

University of Illinois (1)
Control Systems Laboratory
Urbana, Illinois
ATTN D. Alpert

University of Illinois (1)
Digital Computer Laboratory
Urbana, Illinois
ATTN Dr. J. E. Robertson

Air Force Cambridge Research Laboratories (1)
Laurence C. Hanscom Field
Bedford, Massachusetts
ATTN Research Library, CRX2-R

Technical Information Officer (1)
U.S. Army Signal Research and Development Laboratories
Fort Monmouth, New Jersey
ATTN Data Equipment Branch

National Security Agency (1)
Fort George G. Meade, Maryland
ATTN R-4, Howard Campaigne

U.S. Naval Weapons Laboratory (1)
Dahlgren, Virginia
ATTN Head, Compution Division, G. H. Gleissner

National Bureau of Standards (1)
Data Processing Systems Division
Room 239, Building 10
Washington 25, DC
ATTN A. K. Smilow

Aberdeen Proving Ground, Ballistic Research Laboratory (1)
Aberdeen Proving Ground, Maryland
ATTN J. H. Giese, Chief Compution Laboratory

Commanding Officer (1)
ONR Branch Office
John Crerar Library Building
86 East Randloph Street
Chicago 1, Illinois

Commanding Officer (1)
ONR Branch Office
1030 East Green Street
Pasadena, California

Commanding Officer (1)
ONR Branch Office
1000 Geary Street
San Francisco 9, California

National Bureau of Standards (1)
Washington 25, DC
ATTN Mr. R. D. Elbourn

George Washington University (1)
Washinton, DC
ATTN Prof. N. Grisamore

Syracuse University (1)
Electrical Engineering Department
Syracuse 10, New York
ATTN Dr. Stanford Goldman

Princeton University (1)
Electrical Engineering Department
Princeton, New Jersey
ATTN Prof. F. S. Acton

Burroughs Corporation (1)
Research Center
Paoli, Pennsylvania
ATTN R. A. Tracey

Office of Naval Research (1)
Washington 25, DC
ATTN Code 455

Cornell University (1)
Cognitive Systems Research Program
Hollister Hall
Ithaca, New York
ATTN Dr. Frank Rosenblatt

Lockheed Missiles and Space Company (1)
3251 Hanover Street
Palo Alto, California
ATTN W. F. Main

Communications Sciences Laboratory (1)
University of Michigan
180 Frieze Building
Ann Arbor, Michigan
ATTN Gordon E. Peterson

University of Michigan (1)
Ann Arbor, Michigan
ATTN Department of Psychology
Prof. Arthur Melton

University of Michigan (1)
Ann Arbor, Michigan
ATTN Department of Philosophy
Prof. A. W. Burks

University of Pennsylvania (1)
Philadelphia 4, Pennsylvania
ATTN Department of Psychology
Mr. R. Duncan Luce

Carnegie Institute of Technology (1)
Department of Psychology
Pittsburgh 13, Pennsylvania
ATTN Prof. Bert F. Green, Jr.

Massachusetts Institute of Technology (1)
Research Laboratory for Electronics
Cambridge, Massachusetts
ATTN Dr. Marvin Minsky

Stanford University (1)
Stanford, California
ATTN Electronics Laboratory
Prof. John G. Linvill

Stanford University (1)
Stanford, California
ATTN Electronics Laboratory
Prof. Gene Franklin

University of Illinois (1)
Urbana, Illinois
ATTN Electrical Engineering Department
Prof. H. Von Foerster

University of California (1)
Institute of Engineering Research
Berkeley 4, California
ATTN Prof. A. J. Thomasian

National Science Foundation (1)
Program Director for Documentation Research
Washington 25, DC
ATTN Helen L. Brownson

Wayne State University (1)
Detroit, Michigan
ATTN Department of Slavic Languages
Prof. Harry H. Josselson

University of California - LA (1)
Los Angeles 24, California
ATTN Department of Engineering
Prof. Gerald Estrin

Columbia University (1)
New York 27, New York
ATTN Department of Physics
Prof. L. Brillouin

Hebrew University (1)
Jerusalem, Israel
ATTN Prof. Y. Bar-Hillel

Massachusetts Institute of Technology (1)
Cambridge, Massachusetts
ATTN Prof. V. H. Yngve

Massachusetts Institute of Technology (1)
Research Laboratory of Electronics
ATTN Prof. W. McCulloch

University of Illinois (1)
Champaign Urbana, Illinois
ATTN John R. Pasta

Naval Research Laboratory (1)
Washington 25, DC
ATTN Security Systems, Code 5266
Mr. G. Abraham

Zator Company (1)
140½ Mt. Auburn
Cambridge 38, Massachusetts
ATTN R. J. Solomonoff

National Aeronautics and Space Administration (1)
Goddard Space Flight Center
Washington 25, DC
ATTN Arthur Shapiro

Professor Marc Kac (1)
Rockefeller Institute
New York, New York

Cornell University (1)
Ithaca, New York
ATTN Department of Psychology
Prof. Robert B. MacLeod

Cornell University (1)
Ithaca, New York
ATTN Department of Psychology
Prof. Julian Hochberg

Western Reserve University (1)
Cleveland 6, Ohio
ATTN Department of Anatomy - School of Medicine
Prof. Marcus Singer

Cornell University (1)
Ithaca, New York
ATTN Division of Modern Languages
Prof. Charles Hockett

Cornell University (1)
Ithaca, New York
ATTN Department of Physics
Prof. Phillip Morrison

University of Illinois (1)
Urbana, Illinois
ATTN Department of Electrical Engineering
Dr. W. Ross Ashby

National Physical Laboratory (1)
Teddington, Middlesex
England
ATTN Autonomics Division
Dr. A. M. Uttley, Superintendent

University College London (1)
Gower Street
London, W. C. 1, England
ATTN Department of Electrical Engineering
Dr. W. K. Taylor

United Aircraft Corporation (1)
Research Laboratories
East Hartford 8, Connecticut
ATTN Dr. George B. Yntema

Swarthmore College (1)
Swarthmore, Pennsylvania
ATTN Department of Electrical Engineering
Prof. Carl Barus

Neurological Institute of McGill University (1)
3801 University Street
Montreal, Canada
ATTN Dr. Herbert Jasper

Harvard University (1)
Memorial Hall
Cambridge 38, Massachusetts
ATTN Dr. Jacob Beck

University of Michigan (1)
Ann Arbor, Michigan
ATTN Department of Psychology
Dr. James Olds

Diamond Ordnance Fuze Laboratory (1)
Connecticut Ave. & Van Ness St.
Washington 25, DC
ORDTL-012, E. W. Channel

Harvard University (1)
Cambridge, Massachusetts
ATTN School of Applied Science
Dean Harvey Brook

Commanding Officer and Director (1)
U. S. Naval Training Device Center
Port Washington
Long Island, New York
ATTN Technical Library

Office of Naval Research (1)
Washington 25, DC
ATTN Code 450, Dr. R. Trumbull

The University of Chicago (1)
Institute for Computer Research
Chicago 37, Illinois
ATTN Mr. Nicholas C. Metropolis, Director

Wright Air Development Division (1)
Electronic Technology Laboratory
Wright-Patterson Air Force Base, Ohio
ATTN Lt. Col. L. M. Butsch, Jr.
ASRUEB

Laboratory for Electronics, Inc. (1)
1079 Commonwealth Avenue
Boston 15, Massachusetts
ATTN Dr. H. Fuller

Stanford Research Institute (1)
Computer Laboratory
Menlo Park, California
ATTN H. D. Crane

The Rand Corporation (1)
1700 Main Street
Santa Monica, California
ATTN Numerical Analysis Department
Willis H. Ware

University of Oregon (1)
Portland, Oregon
ATTN Medical School
Dr. Tunturi

Zator Company (1)
140½ Mt. Auburn Street
Cambridge 38, Massachusetts
ATTN Calvin N. Mooers

Massachusetts Institute of Technology (1)
Cambridge 39, Massachusetts
ATTN Prof. John Mc Carthy, 26-007B

Office of Naval Research (1)
Washington 25, DC
ATTN Code 430

Carnegie Institute of Technology (1)
Pittsburgh, Pennsylvania
ATTN Director, Computation Center
Alan J. Perlis

Rome Air Development Center, RCOR (1)
DCS/Operations, USAF
Griffiss Air Force Base, New York
ATTN Irving J. Gabelman

Air Force Office of Scientific Research (1)
Directorate of Information Sciences
Washington 25, DC
ATTN Dr. Harold Wooster

Hunter College (1)
New York 21, New York
ATTN Dean Mina Rees

Stanford Research Institute (1)
Menlo Park, California
ATTN Applied Physics Laboratory
Dr. Charles Rosen

University of California (1)
Berkeley, California
ATTN Department of Mathematics
Prof. H. J. Bremermann

National Bureau of Standards (1)
Washington 25, DC
ATTN Miss Ida Rhodes, 220 Stucco Building

University of Saskatchewan (1)
College of Engineering
Saskatoon, Canada
ATTN H. C. Ratz

Northeastern University (1)
360 Huntington Avenue
Boston, Massachusetts
ATTN Prof. L. O. Dolansky

IBM Corporation (1)
Federal Systems Division
326 E. Montgomery Avenue
Rockville, Maryland
ATTN Dr. Stanley Winkler

L. G. Hanscom Field/AF-CRL-CRRB/ (1)
Bedford, Massachusetts
ATTN Dr. H. H. Zschirnt

Rome Air Development Center (1)
Griffiss Air Force Base
Rome, New York
ATTN Mr. Alan Barnun

Armour Research Foundation (1)
10 West 35th Street
Chicago 16, Illinois
ATTN E. E. Research Department
Mr. Scott Cameron

Department of the Army (1)
Office of the Chief of Research and
Development
Pentagon, Room 3D442
Washington 25, DC
ATTN Mr. L. H. Geiger

Cambridge Language Research Unit (1)
20 Millington Road
Cambridge, England
ATTN Mrs. Margaret M. Braithwaite

Carnegie Institute of Technology (1)
Systems and Communication Sciences
Pittsburgh 13, Pennsylvania
ATTN Dr. Allen Newell

Cornell University (1)
Cognitive Systems Research Program
Cornell Computing Center
Ithaca, New York
ATTN Prof. H. D. Block

Royal Aircraft Establishment (1)
Farnborough, Hampshire, England
ATTN Mathematics Department
Mr. R. A. Fairthrone
Minister of Aviation

IBM Research (1)
Yorktown Heights, New York
ATTN Hans Peter Luhn

Library of Congress (1)
Washington 25, DC
ATTN John Sherrod

National Biomedical Research Foundation, Inc. (1)
8600 16th Street, Suite 310
Silver Spring, Maryland
ATTN Dr. R. S. Ledley

National Bureau of Standards (1)
Washington 25, DC
ATTN Mrs. Ethel Marden

Department of Commerce (1)
U. S. Patent Office
Washington 25, DC
ATTN Mr. Herbert R. Koller

Thompson Ramo Woolridge Inc. (1)
8433 Fallbrook Avenue
Canoga Park, California
ATTN D. R. Swanson

Rand Corporation (1)
1700 Main Street
Santa Monica, California
ATTN Library

University of Chicago (1)
Committee on Mathematical Biology
Chicago, Illinois
ATTN Prof. H. D. Landahl

University of Pennsylvania (1)
Moore School of Electrical Engineering
200 South 33rd Street
Philadelphia 4, Pennsylvania
ATTN Miss Anna Louise Campion

Department of the Army (1)
Office of the Assistant COFD for Intellegence
Room 2B529, Pentagon
Washington, DC
ATTN John F. Kullgren

Mr. Robert F. Samson (1)
Directorate of Intelligence and Electronic
Warfare
Griffiss Air Force Base
Rome, New York

Army Research Office OCR & D (1)
Department of Army
Washington 2, DC
ATTN Mr. Gregg Mc Clurg

Division of Automatial Data Processing/AOP/ (1)
Department of State
Washington 25, DC
ATTN F. P. Diblasi, 19A16

Mr. Paul W. Howerton (1)
Room 1053 M. Building
Code 163
CIA
Washington, DC

University of Pennsylvania (1)
Mechanical Languages Projects
Moore School of Electrical Engineering
Philadelphia 4, Pennsylvania
ATTN Dr. Saul Gorn, Director

Arthur D. Little, Inc. (1)
Acorn Park
Cambridge 40, Massachusetts
ATTN Dr. Vincent Giuliano

Mr. Bernard M. Fry, Deputy Head (1)
Office of Science Information Service
National Science Foundation
1951 Constitution Avenue, N. W.
Washington 25, DC

International Business Machines Corporation (1)
Advanced Systems Development Division
San Jose 14, California
ATTN I. A. Warheit

Cornell University (1)
Ithaca, New York
ATTN Department of Mathematics
Harry Kesten

Applied Physics Laboratory (1)
Johns Hopkins University
8621 Georgia Avenue
Silver Spring, Maryland
ATTN Document Library

Bureau of Supplies and Accounts, Chief (1)
Navy Department
Washington, DC
ATTN Code W3

Officer in Charge (1)
U. S. Naval Photographic Interpretation Center
4301 Suitland Road
Suitland, Maryland
ATTN Mr. J. Pickup

University of Pennsylvania (1)
Moore School of Engineering
Philadelphia 4, Pennsylvania
ATTN Dr. Noah S. Prywes

National Aeronautics and Space Administration (1)
Goddard Space Flight Center
Greenbelt, Maryland
ATTN Chief, Data Systems Division
C. V. L. Smith

Rabinow Engineering Company, Inc. (1)
7712 New Hampshire Avenue
Washington 12, DC

National Security Agency (1)
Fort George G. Meade, Maryland
ATTN R.-42, R. Wiggington

Stanford University (1)
Stanford, California
ATTN Department of Mathematics
Prof. George E. Forsythe

University of Chicago (1)
Chicago, Illinois
ATTN Committee on Mathematical Biology
Peter H. Greene

Federal Aviation Agency (1)
Bureau of Research and Development
Washington 25, DC
ATTN RD-375, Harry Hayman

Veterans Administration (1)
Department of Medicine and Surgery
Washington 25, DC
ATTN Research and Development Division
H. Frieburger

Federal Aviation Agency (1)
Bureau of Research and Development Center
Atlantic City, New Jersey
ATTN Simon Justman

Cornell Aeronautical Laboratory, Inc. (1)
P. O. Box 235
Buffalo 21, New York
ATTN Systems Requirements Department
A. E. Murray

Institute for Space Studies (1)
475 Riverside Drive
New York 27, New York
ATTN Mr. Albert Arking

Mr. Donald F. Wilson (1)
Code 5144
Naval Research Laboratory
Washington 25, DC

University of California (1)
Berkely 4, California
ATTN Department of Engineering
Prof. J. R. Singer

Navy Management Office (1)
Data Processing Systems Division
Department of the Navy
Washington 25, DC
ATTN Mr. J. Smith

Lincoln Laboratory (1)
Massachusetts Institute of Technology
Lexington 73, Massachusetts
ATTN Library

University Di Milano (1)
Centro Di Cibernetica
Via Festa Del Perdono, 3
Milano, Italy
ATTN Prof. Silvio Ceccato

Brookhaven National Laboratory (1)
Upton, Long Island, New York
ATTN Dr. Yoshio Shimamoto

Sperry Phoenix Company (1)
Phoenix, Arizona
ATTN Technical Librarian

Instituto Di Fisica Dell Universita (1)
Genova, Italy
ATTN Prof. A. Gamba

Ryuichi Kono (1)
Milsubishi Electric Manufacturing
Company, Ltd.
Kamakura Works
325 Kamimackiya Kumakura
Kanagawa-Ken, Japan

Howard University (1)
Washington 1, DC
ATTN Psychology Department
Dr. C. R. Porter

Advanced Systems Research Group (1)
North American Aviation Company
4300 E. 5th Avenue
Columbus, Ohio
ATTN Dr. George N. Omstein

Mr. Gordon Stanley (1)
7685 South Sheridan Court
Littleton, Colorado

University of California (1)
Berkeley, California
ATTN Lawrence Radiation Laboratory
Dr. Milton E. Rose

The Johns Hopkins University (1)
8621 Georgia Avenue
Silver Spring, Maryland
ATTN Applied Physics Laboratory
A. J. Cote, Jr.

University of Michigan (1)
Ypsilanti, Michigan
ATTN Willow Run Laboratories
Mr. Paul Metzelaar

Cornell University (1)
Ithaca, New York
ATTN Department of Psychology
Prof. T. A. Ryan

Mc Gill University (1)
Montreal, Quebec
Canada
ATTN Department of Psychology
Prof. Donald Hebb

Swarthmore College (1)
Swarthmore, Pennsylvania
ATTN Department of Psychology
Prof. Hans Wallach

California State Polytechnic College (1)
San Luis Obispo, California
ATTN Dr. James T. Culbertson

Stanford Research Institute (1)
Menlo Park, California
ATTN Computer Laboratory
W. H. Kautz, Sr., Research Engineer

Rechts-U. Staatsu (1)
Fakultat D. Universitat
Worthmannsplatz 1,
Freiburg 1, Br. Germany
ATTN Prof. F. A. Hayek

Commanding Officer (1)
Rome Air Development Center
Griffiss Air Force Base
Rome, New York
ATTN Lt. Roger Geesey, RCWID

Institute for Space Studies (1)
475 Riverside Drive
New York 27, New York
ATTN Dr. Hong Yee Chiu

Institute for Defense Analysis (2)
Communications Research Division
76½ Nassau Street
Princeton, New Jersey
ATTN Prof. J. B. Rosser, Director

Dr. B. Mandelbrot (1)
Littaver G-51
Harvard University
Cambridge 38, Massachusetts

Advanced Research (1)
3946 Fabian Way
Palo Alto, California
ATTN W. W. Bledsoe

Aeronutronics (1)
Ford Road
Newport Beach, California
ATTN J. K. Hawkins

Cornell University Library (1)
Ithaca, New York
ATTN Central Serial Record Department

University of Rochester (1)
Center for Brain Research
Rochester 20, New York
ATTN Prof. E. R. John

Massachusetts Institute of Technology (1)
Lincoln Laboratory
Lexington 73, Massachusetts
ATTN Dr. B. Farley

Massachusetts Institute of Technology (1)
Lincoln Laboratory
Lexington 73, Massachusetts
ATTN Dr. Oliver Selfridge

Dr. John Hay (1)
62 Kensington Avenue
Northampton, Massachusetts

University of California (1)
Western Management Science Institute
Graduate School of Business Administration
Los Angeles 24, California
ATTN Mr. Earl B. Hunt

Astropower, Inc. (1)
2968 Randolph Street
Costa Misa, California
ATTN Dr. R. D. Joseph, Principal
Mathematician

Philco Corporation (1)
Philadelphia, Pennsylvania
ATTN Dr. Peter M. Kelly

Ryuichi Kono (1)
Mitsubishi Electric Manufacturing Co., Ltd.
Electronics Works
80 Nakano, Minami Shimizu
Amagasaki
Hyogo Perfecture, Japan

ONR Special Representative (1)
c/o Hudson Laboratories
Columbia University
145 Palisade Street
Dobbs Ferry, New York

Radio Corporation of America (1)
RCA Laboratories
David Sarnoff Research Center
Princeton, New Jersey
ATTN Mr. Saul Amarel

Research Division (1)
Kollsman Instrument Corporation
80-08 45th Avenue
Elmhurst 73, New York
ATTN Mr. Seymour T. Levine

Ohio State University (1)
1314 Kinnear Road
Columbus 12, Ohio
ATTN Mr. Don Meyer

Operations Research Incorporated (1)
8605 Cameron Street
Silver Spring, Maryland
ATTN Mr. Howard Eisner

Office of Research and Development (1)
U. S. Department of Commerce
Patent Office
Washington 25, DC
ATTN Allan Kiron

U. S. Naval Ordnance Test Station (1)
Pasadena Annex
3202 E. Foothill Boulevard
Pasadena 8, California
ATTN L. Freinkel

Air Force Office of Scientific Research (1)
Information Research Division
Washington 25, DC
ATTN R. W. Swanson

Sandia Corporation (1)
Sandia Base
Albuquerque, New Mexico
ATTN Mr. William Michael Dante

Texas Instruments Incorporated (1)
Corporate Research and Engineering
P. O. Box 5474
Dallas 22, Texas
ATTN Technical Reports Service

Sandia Corporation (1)
Sandia Base
Albuquerque, New Mexico
ATTN Dr. G. William Rollosson
Head, Advanced Development Division
Organization 7223